REMARKS

Reconsideration is respectfully requested in view of the above amendments and following remarks. Claims 1-6, 9, 10, 14 and 18 have been canceled without prejudice or disclaimer. Claims 7, 8, 11, 13 and 15-17 have been rewritten in independent form. No new matter has been added. Claims 7, 8, 11-13 and 15-17 are pending.

Specification

The Examiner has objected to the title. The title has been amended to read "MAGNETO-OPTICAL RECORDING MEDIUM HAVING MULTIPLE MAGNETIC LAYERS".

Claim rejections - 35 U.S.C. § 102

Claims 1-6, 9, 10, 14 and 18 are rejected under 35 U.S.C. 102(e) as being anticipated by Nishikiori et al. (US 6,018,511). This rejection is rendered moot, as claims 1-6, 9, 10, 14 and 18 have been canceled. Applicants do not concede the correctness of the rejection. Withdrawal of the rejection is respectfully requested.

Claim rejections - 35 U.S.C. § 103

Claims 11-13, 15 and 17 are rejected under 35 U.S.C. 103(a) as being unpatentable over Nishikiori et al. (US 6,018,511) further in view of Murakami et al. (US 6,519,211). Claims 11, 13, 15 and 17 have been rewritten in independent form. It is hereby confirmed by applicants that the Murakami reference and the invention of the present application were commonly owned when the invention was made. Applicants also note that the priority application for the Murakami reference was not published more than one year before the filing of the present

application. The present application claims priority under 35 U.S.C. 119 to Japanese Application Serial Number 2000-310394, filed October 11, 2000. Applicants file herewith a verified translation of JP 2000-310394 to perfect priority and remove the Murakami published priority application as a potential prior art reference. Applicants do not concede the correctness of the rejection. Withdrawal of the rejection is respectfully requested.

In view of the above, favorable reconsideration in the form of a notice of allowance is requested. Any questions or concerns regarding this communication can be directed to the undersigned attorney, Douglas P. Mueller, Reg. No. 30,300, at (612)371.5237.

Respectfully submitted,

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[TITLE OF THE INVENTION]

MAGNETO-OPTICAL RECORDING MEDIUM AND REPRODUCING METHOD

[CLAIMS]

[Claim 1]

A magneto-optical recording medium comprising at least a first magnetic layer, a second magnetic layer, and a third magnetic layer that are laminated successively, wherein the first magnetic layer has a smaller domain wall coercive force as compared with those of the second and third magnetic layers, and the third magnetic layer is a perpendicular magnetization film that has a greater coercive force at room temperature as compared with the first magnetic layer,

wherein

the second magnetic layer has a Curie temperature T_{C2} lower than a Curie temperature T_{C1} of the first magnetic layer and a Curie temperature T_{C3} of the third magnetic layer, and

the second magnetic layer is an in-plain magnetic film at room temperature, has a characteristic of making a transition from the in-plain magnetic film to a perpendicular magnetization film as temperature rises, and is in a perpendicular magnetization state in a temperature range to the Curie temperature T_{C2} from a temperature at which the second magnetic layer makes a transition from the in-plain magnetization film to the perpendicular magnetization film.

[Claim 2]

The magneto-optical recording medium according to claim 1,

wherein the second magnetic layer has a temperature at which the second magnetic layer makes a transition from the in-plain magnetic film to the perpendicular magnetization film in a temperature range between a temperature 100 degrees lower than the Curie temperature T_{C2} of the second magnetic layer to the Curie temperature T_{C2} of the second magnetic layer.

[Claim 3]

The magneto-optical recoding medium according to claim 1 or 2, wherein the first, second, and third magnetic layers are

exchange-coupled in a temperature range greater than the temperature at which the second magnetic layer makes a transition from the in-plain magnetization film to the perpendicular magnetization film and not higher than the Curie temperature T_{C2} of the second magnetic layer.

[Claim 4]

The magneto-optical recording medium according to any one of claims 1 to 3, further comprising a non-magnetic layer laminated so as to be adjacent to the second magnetic layer.

[Claim 5]

The magneto-optical recording medium according to any one of claims 1 to 4, wherein the first magnetic layer is composed of a plurality of magnetic films.

[Claim 6]

The magneto-optical recording medium according to any one of claims 1 to 5, wherein the magnetic films composing the first magnetic layer are in-plain magnetization films at least at room temperature.

[Claim 7]

The magneto-optical recording medium according to any one of claims 1 to 5, wherein the magnetic films composing the first magnetic layer are perpendicular magnetization films at least at room temperature.

[Claim 8]

The magneto-optical recoding medium according to claim 5, wherein a plurality of magnetic films composing the first magnetic layer have Curie temperatures different from one another.

[Claim 9]

The magneto-optical recoding medium according to any one of claims 1 to 5, further comprising a fourth magnetic layer having a Curie temperature in a temperature range of not lower than the Curie temperature T_{C2} of the second magnetic layer and not higher than the Curie temperature T_{C1} of the first magnetic layer, the fourth magnetic layer being laminated between the first magnetic layer and the second magnetic layer.

[Claim 10]

A method for reproducing recorded information from the magneto-optical recording medium according to any one of claims 1 to 9, comprising the step of:

projecting a light beam to the medium while moving the light beam relative to the medium so that temperature distribution with gradient is formed on the magneto-optical recording medium, so as to move a domain wall between magnetic domains that are transferred from the third magnetic layer to the first magnetic layer via the second magnetic layer in the magneto-optical recording medium, and to detect a change in a polarization plane of a reflected light of the light beam from the medium, whereby recorded information is reproduced.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical field to which the invention pertains]

The present invention relates generally to a magneto-optical recording medium to/from which information is recorded/reproduced with a laser beam by utilizing magneto-optical effects.

[0002]

[Prior Art]

Technologies have been developed vigorously relating to, as a repetitively rewritable high-density recording medium, a magneto-optical recording medium in which magnetic microdomains are recorded in a magnetic thin film by utilizing the thermal energy of a laser beam and from which signals are reproduced by utilizing magneto-optical effects, as well as relating to a recording/reproducing device. Such a magneto-optical recording medium has a defect such that reproduction characteristics are impaired in the case where diameters and intervals of recording bits functioning as recording magnetic domains decrease relative to a beam diameter of a light beam converged onto the medium. This is because a beam spot of the light beam formed by converging the light beam onto a target recording bit also falls on adjacent recording bits, thereby making it impossible to reproduce individual recording bits separately.

[0003]

To solve the foregoing defect, attempts to improve the recording

density have been made by devising the configuration of the recording medium and the reproducing method, and the super-resolution reproducing method, the reproducing method in which magnetic domains are enlarged so as to be reproduced (hereinafter referred to as magnetic-domain enlarging-reproducing method) by utilizing the domain wall movement, etc. have been proposed. The following description will depict the magnetic-domain enlarging-reproducing method disclosed by JP 6(1994)-290496A (hereinafter referred to as conventional example), while referring to a configuration drawing of FIG. 8.

[0004]

In the magneto-optical recording medium, magnetic films of a multilayer structure are exchange-coupled, and amplitudes of reproduction signals are widened by enlarging recording magnetic microdomains of a recording layer 83 in a magnetic-domain enlarging layer 81, whereby consequently high density recording is enabled. It should be noted that arrows in each layer indicate directions of sub-lattice magnetizations of transition metals in the films. Between magnetic domains whose magnetization directions are opposite to each other, a domain wall 84 is formed in each layer. A hatched portion in a part of an intermediate layer 82, in which no arrow is shown, indicates a portion that has lost the magnetic order since it has been heated to a Curie temperature or above.

[0005]

Essential requirements of the magneto-optical recording medium are the following four points:

1. the medium has a recording layer 83 that maintains microdomains stably in a temperature range from room temperature to a temperature for reproduction;
2. the recording layer 83, the intermediate layer 82, and the magnetic domain enlarging layer 81 are exchange-coupled at least at around the Curie temperature of the intermediate layer 82;
3. the intermediate layer 82 loses magnetic order at a temperature exceeding its Curie temperature, and in a temperature range above the same, it breaks the exchange-coupling from the recording layer 83 to the magnetic-domain enlarging layer 81;
4. the magnetic-domain enlarging layer 81 has a small domain wall coercive force, and a domain-wall-energy gradient is generated according to the temperature gradient. Therefore, in a region where the

exchange-coupling is broken due to the intermediate layer 82, the domain wall 84 moves from a portion transferred from the magnetic domain in the recording layer 83 as a starting point. Consequently, the magnetizations in the foregoing region are directed in the same direction.

[0006]

In Fig. 8, in the case where the disk is moved rightward in the drawing while the magneto-optical recording medium is irradiated with a laser beam, since the disk moves at a great linear velocity, a position at which a film temperature has a maximum value is behind the center of a beam spot in a beam spot moving direction. A domain-wall-energy density σ_1 in a magnetic-domain enlarging layer 81 usually decreases as the temperature rises, and becomes 0 at a temperature at or higher than the Curie temperature. Therefore, if there is a temperature gradient, the domain-wall-energy density σ_1 is lower on the high temperature side.

[0007]

Here, a force F_1 expressed by the following equation is applied to domain walls in respective layers that are present at a position in the radial direction on the medium:

[0008]

$$F_1 = -d\sigma_1/dx$$

The force F_1 is applied so as to move the domain wall toward a portion having a lower domain-wall-energy. Therefore, in the magnetic-domain enlarging layer 81, having a lower domain-wall coercive force and a greater domain wall movement degree as compared with the other magnetic layers, a domain wall is moved by the force F1 to a side where the domain-wall-energy is lower, when the exchange coupling force from the intermediate layer 82 is blocked.

[0009]

In Fig. 8, before the laser beam is projected to the disk, that is, when the three magnetic layers are exchange-coupled in the portion at room temperature and the magnetic domains recorded in the recording layer 83 are transferred to the magnetic-domain enlarging layer 81. Here, a domain wall 4 is present between magnetic domains having opposite magnetization directions in each layer. In a portion where the film temperature is not lower than the Curie temperature of the intermediate layer 82, the magnetization of the intermediate layer 82 disappears, and the exchange

coupling between the magnetic-domain enlarging layer 81 and the recording layer 83 breaks. Therefore, the magnetic-domain enlarging layer 81 loses a force for maintaining the domain wall, and allows the domain wall to move toward a higher temperature side due to the force F1 applied to the domain wall. The velocity for moving the domain wall is sufficiently high as compared with the moving velocity of the medium. Consequently, a magnetic domain greater than a magnetic domain stored in the recording layer 83 is transferred to the magnetic-domain enlarging layer 81.

[0010]

[Problems to be solved by the invention]

As described in the foregoing conventional example, a medium in which a domain wall in a circumferential direction is enlarged by a temperature gradient caused by a laser beam has a temperature gradient in a radial direction as well, and a problem arises in that a domain wall moves from a magnetic domain present in an adjacent track. Therefore, a technique in which the domain wall movement in a radial direction is prevented by magnetic separation of a target track from the adjacent tracks has been proposed. Two main schemes are shown below:

[0011]

(i) forming rectangular guide grooves on a substrate, so as to separate tracks with the grooves; and

(ii) achieving magnetic separation with use of an in-plain magnetization film formed by annealing of the first magnetic layer in an adjacent track.

In the case of (i), films actually are formed in step-like portions thereby connecting magnetic layers with each other. Therefore, it is difficult to achieve complete magnetic separation and the domain wall movement is hindered. As to the case of (ii), an industrially applicable scheme for mass production has not been known, and the annealing of recording layers of adjacent tracks is disadvantageous with a view to high-density recording.

[0012]

The present invention is made to solve the foregoing problems of the prior art, and it is an object of the present invention to break a magnetic association with an adjacent track that hinders the domain wall movement upon the enlargement and reproduction of a magnetic domain, and to provide a magneto-optical recording medium that realizes excellent movement of a domain wall and excellent enlargement of a magnetic

domain.

[0013]

Additionally, the following problems can be overcome. In the conventional method, since the magnetic-domain enlarging layer 81 and the intermediate layer 82 are perpendicular magnetization films, magnetostatic coupling forces due to floating magnetic fields from the reproduction layer and the intermediate layer in an adjacent track are exerted to the magnetic-domain enlarging layer 81, in a region in which the exchange coupling from the recording layer 83 at a temperature of not less than T_{C2} to the magnetic-domain enlarging layer 1 is broken. Besides, within a spot diameter, in the case where the magnetic-domain enlarging layer 81 outside a magnetic domain to be reproduced is in a perpendicular magnetization state, extra noises for reproduction signals are generated. The present invention suppresses the foregoing noises, thereby providing a magneto-optical recording medium excellent in reproduction signal characteristics, and a method for reproducing the same.

[0014]

[Means for solving problems]

A magneto-optical recording medium is characterized by including at least a first magnetic layer, a second magnetic layer, and a third magnetic layer that are laminated successively, wherein the first magnetic layer has a smaller domain-wall coercive force as compared with those of the second and third magnetic layers, and the third magnetic layer is a perpendicular magnetization film that has a greater coercive force at room temperature as compared with the first magnetic layer. In the magneto-optical recording medium, the second magnetic layer has a Curie temperature T_{C2} lower than a Curie temperature T_{C1} of the first magnetic layer and a Curie temperature T_{C3} of the third magnetic layer, and the second magnetic layer is an in-plain magnetic film at room temperature, has a characteristic of making a transition from the in-plain magnetic film to a perpendicular magnetization film as temperature rises, and is in a perpendicular magnetization state in a temperature range between a temperature at which the second magnetic layer makes a transition from the in-plain magnetization film to the perpendicular magnetization film and the Curie temperature.

[0015]

The magneto-optical recording medium is characterized in that the second magnetic layer has a temperature at which the second magnetic

layer makes a transition from the in-plain magnetic film to the perpendicular magnetization film in a temperature range between a temperature 100 degrees lower than the Curie temperature T_{C2} of the second magnetic layer to the Curie temperature T_{C2} of the second magnetic layer.

[0016]

The magneto-optical recoding medium is characterized in that the first, second, and third magnetic layers are exchange-coupled in a temperature range greater than the temperature at which the second magnetic layer makes a transition from the in-plain magnetization film to the perpendicular magnetization film and not higher than the Curie temperature T_{C2} of the second magnetic layer.

[0017]

The magneto-optical recording medium is characterized by further including a non-magnetic layer adjacent to the second magnetic layer.

[0018]

The magneto-optical recording medium is characterized in that the first magnetic layer is composed of a plurality of magnetic films. In the magneto-optical recording medium according to claim 1 or 2, the first magnetic layer is an in-plain magnetization film.

[0019]

The magneto-optical recording medium is characterized in that the magnetic films composing the first magnetic layer are in-plain magnetization films at least at room temperature.

[0020]

The magneto-optical recording medium is characterized in that the magnetic films composing the first magnetic layer are perpendicular magnetization films at least at room temperature.

[0021]

The magneto-optical recoding medium is characterized in that a plurality of magnetic films composing the first magnetic layer have Curie temperatures different from one another.

[0022]

The magneto-optical recoding medium is characterized by further including a fourth magnetic layer having a Curie temperature in a temperature range of not lower than the Curie temperature T_{C2} of the second magnetic layer and not higher than the Curie temperature T_{C1} of the

first magnetic layer, the fourth magnetic layer being laminated between the first magnetic layer and the second magnetic layer.

[0023]

A method for reproducing recorded information from the magneto-optical recording medium is characterized by including the step of projecting a light beam to the medium while moving the light beam relative to the medium so that temperature distribution with gradient is formed on the magneto-optical recording medium, to move a domain wall between magnetic domains that are transferred from the third magnetic layer to the first magnetic layer via the second magnetic layer in the magneto-optical recording medium, and to detect a change in a polarization plane of a reflected light of the light beam from the medium, whereby recorded information is reproduced..

[0024]

[Mode for carrying out the invention]

First, principles of the present invention are described, with reference to Figs. 1 and 2. Fig. 1 is a schematic cross-sectional view (in a laser beam traveling direction) of a magneto-optical recording medium of the present invention, and Fig. 2 is a schematic cross-sectional view (in a radial direction) of the magneto-optical recording medium of the present invention. A magnetic layer of the medium is composed of a first magnetic layer (magnetic-domain enlarging layer 11), a second magnetic layer (intermediate layer 12), and a third magnetic layer (recording layer 13) that are laminated successively. Arrows in each layer indicate directions of sub-lattice magnetizations of transition metals in the films. In each layer, between magnetic domains whose magnetization directions are opposite to each other, a domain wall is formed. A hatched portion in a part of an intermediate layer 12 without arrows indicate a portion that has lost the magnetic order since its film temperature has reached a Curie temperature T_{C2} of the intermediate layer 12 or above.

[0025]

In the present invention, as compared with the prior art, the intermediate layer 12 has magnetic characteristics that are adjusted so that it is in an in-plain magnetization state at room temperature, and as the temperature rises, it makes a transition from the in-plain magnetization film to a perpendicular magnetization film (the temperature upon the transition is hereinafter referred to as a critical point). In the reproduction

in the present invention, the exchange coupling between the magnetic-domain enlarging layer 11 and the recording layer 13 is not established in a portion in which the film temperature is room temperature or does not reach the critical point, since the intermediate layer 12 is an in-plain magnetization film. When a laser beam is incident and the film temperature rises to the critical point, the intermediate layer 12 becomes a perpendicular magnetization state, and a recording magnetic domain of the recording layer 13 is transferred to the magnetic-domain enlarging layer 11, whereby the exchange coupling is realized.

[0026]

In other words, on adjacent tracks and tapered faces of walls of lands, the intermediate layer 12 and the magnetic-domain enlarging layer 11 are in an in-plain magnetization state since the film temperature is low. Therefore, the magnetic association from an adjacent track can be broken, and the generation of a floating magnetic field from an adjacent track can be controlled, whereby the reduction of cross talk can be achieved. The following will describe in detail a specific embodiment in which the present invention is applied, while referring to the drawings.

[0027]

(Embodiment 1)

Targets of Si doped with B, GdFeCo, TbFe, Fe, Co, and AlTi were placed in a direct current magnetron sputtering device. On a substrate holder, a land-groove substrate obtained by injection molding of a polycarbonate material, on which guide grooves with a width of 0.6 μm and a depth of 55 nm for tracking use was fixed. Then, a chamber of the device was vacuumed by a cryopump so as to have a high vacuum of not more than 1×10^{-5} Pa, and Ar gas was introduced into the chamber while the vacuuming was continued until a degree of vacuum of 0.3 Pa was obtained. A SiN layer as an interference layer 10 was formed so as to have a thickness of 80 nm, while the substrate was rotated. Then, successively, a magnetic-domain enlarging layer 11 as a first magnetic layer was formed with GdFeCoAl so as to have a thickness of 40 nm (Curie temperature T_{C1} = 260°C), an intermediate layer 12 as a second magnetic layer was formed with GdFeAl so as to have a thickness of 10 nm (T_{C2} = 150°C), a recording layer 13 as a third magnetic layer was formed with TbFeCo so as to have a thickness of 80 nm (T_{C3} = 300°C), and a protective layer was formed with SiN so as to have a thickness of 50 nm. It should be noted that when the

SiN layer was formed, N_2 gas was introduced in addition to Ar gas, and the formation was carried out by direct current reactive sputtering. The magnetic layers were formed by applying direct power to the targets of GdFeCo, TbFe, Fe, Co, and AlTi. Under the same film formation conditions, a medium as a comparative example 1 was formed by forming, on a disk substrate with the same configuration as that of the present embodiment, a configuration in which the intermediate layer 12 was a perpendicular magnetization film; that is, by forming thereon an interference layer with SiN so as to have a thickness of 80 nm, a magnetic-domain enlarging layer 1 with GdFeCoAlTi so as to have a thickness of 40 nm (TC1 = 260°C), an intermediate layer 2 with TbFe so as to have a thickness of 10 nm (T_{C2} = 150°C, a recording layer 3 with TbFeCo so as to have a thickness of 80 nm (T_{C3} = 300°C), and a protective layer with SiN so as to have a thickness of 50 nm.

[0028]

Film thicknesses of the foregoing layers are examples, and the numerical values thereof are not limited particularly as long as the contents described below regarding the present embodiment can be achieved. Recording/reproduction characteristics were measured as to the magneto-optical recording media thus obtained. A recording/reproducing device used in the measurement was an optical system in a normal magneto-optical disk recording/reproducing device, and recording/reproduction using a light source with a laser wavelength of 660 nm was carried out by driving a medium at a linear velocity of 1.5 m/s. In the recording, after heating to not lower than the Curie temperature of the third magnetic layer, by projecting a pulse laser beam with a duty of 33 % at 10 mW, while modulating a magnetic field at ±350 Oe, repetitive patterns of upward-directed and downward-directed magnetizations corresponding to the modulation of the magnetic field were formed. Magnetic domains, each having a recording length of 0.2 μm, were recorded in Example 1 and Comparative Example 1 by the foregoing method, and the reproduction power characteristics were measured so that magnetic-domain enlargement reproduction was evaluated.

[0029]

The reproduction power dependency of signal-to-noise ratios (C/N ratios) determined as results of the measurement is shown in FIG. 3. It should be noted that as Comparative Example 2, a medium was formed by

subjecting adjacent tracks on both sides of a target track to annealing with a DC light at 10 mW in a magneto-optical recording medium of Comparative Example 1, and recording/reproduction of signals were performed. Obtained measurement results also are shown.

[0030]

In Fig. 3, in the magneto-optical recording medium of Example 1, a portion of the films was heated to the Curie temperature Tc_2 of the second magnetic layer when the reproduction power was in the vicinity of 1 mW, and the domain wall movement occurred in the magnetic-domain enlarging layer 11 when the reproduction power was not less than 1 mW. Therefore, signals of a mark length of 0.2 μm corresponding to a cycle that is not higher than a diffraction limit of light were reproducible, and a C/N ratio of 40 dB was observed.

[0031] On the other hand, as to Comparative Example 1, since signals at a 20 dB level were detected, it can be seen that the magnetic-domain enlargement occurred, but the domain wall movement occurred not only in the laser beam traveling direction but also to adjacent tracks and tapered land side-walls, thereby hindering stable reproduction of signals.

[0032]

As to Comparative example 2 in which adjacent tracks were subjected annealing so that the domain wall movement from an adjacent tracks was suppressed, a C/N ratio of approximately 36 dB was observed.

[0033]

Further, it was confirmed that since Example 1 exhibited a greater C/N ratio as compared with that in Comparative Example 2, the magnetic domain enlargement occurred in a greater area in Example 1 as compared with a medium obtained by annealing a conventional disk. This difference increased in a substrate with a smaller track pitch width particularly. In other words, the magnetic domain enlargement extended not only in the laser traveling direction but also in the radial direction. This can be explained as follows.

[0034]

In the conventional technique, since the exchange coupling is formed in a temperature range from room temperature to a temperature Tc_2 at which the intermediate layer loses magnetic order, the magnetic moment is aligned stably in the same direction as that of the recording layer 13, even though it does not have a coercive force. However, using the foregoing

intermediate layer 12 of the present invention, the magnetic-domain enlarging layer 11 cannot maintain the magnetization direction of the recording layer in a temperature range from room temperature to the critical point.

[0035]

Since GdFeCoAlTi used for forming the magnetic-domain enlarging layer 11 has an extremely great domain-wall-energy density, it forms microdomains in the magnetic-domain enlarging layer 11, and an increase in an area of a domain wall is disadvantageous from the viewpoint of energy, resulting in that a magnetic domain has difficulty in existing unless it has an area not less than a certain predetermined area. Then, when a magnetic domain transferred from the recording layer 13 by the irradiation with a laser is generated therein, it is considered that a driving force for enlarging a magnetic domain to a size such that the magnetic domain can stably exists is generated in the magnetic-domain enlarging layer 11. Particularly, a force for moving a domain wall works in the laser traveling direction due to the temperature distribution.

[0036]

The present invention not only enables the magnetic breaking without annealing or separating adjacent tracks with grooves, but also is effective in obtaining greater signals. Additionally, since the magnetic-domain enlarging layer 11 except for the magnetic domain to be reproduced is in the in-plain magnetization state within a spot diameter, it masks magneto-optical signals. Therefore, it is possible to suppress unnecessary noises for reproduction signals.

[0037]

(Embodiment 2)

Fig. 4 is a view illustrating a configuration of a magneto-optical recording medium of Embodiment 2. This has the same configuration as that of Embodiment 1 except that a reproduction layer 45 is formed between the interference layer and the magnetic-domain enlarging layer 1 formed on a substrate, and a fourth magnetic layer is provided between the magnetic-domain enlarging layer 1 and the intermediate layer 2. Here, to avoid confusion, the fourth magnetic layer is described as a control layer 44. The reproduction layer 45 was formed with a rare earth-transition metal amorphous alloy like the other magnetic layers, for instance, GdCo, GdFeCo, GdFeCoAl, GdFe, NdGdFeCo, etc. that has a Curie temperature higher than

that of the magnetic-domain enlarging layer 41.

[0038]

The provision of a plurality of magnetic films including the reproduction layer enables reproduction of signals with greater amplitudes. Considering the domain wall movement, the magnetic-domain enlarging layer 41 preferably is made of a material having a great temperature gradient of the domain-wall-energy density, and the domain-wall-energy density exhibits maximum variation at a temperature immediately below the Curie temperature. Therefore, a layer having a relatively low Curie temperature is suitable for forming the magnetic-domain enlarging layer 41. However, it is known that a magnetic thin film material having a low Curie temperature has a small Kerr rotation angle. Therefore, since a small Kerr rotation angle leads to a decrease in a carrier value of signals, it is advantageous that a recording film with a higher Curie temperature is used for forming a magnetic layer closest to the substrate on which the laser beam is incident.

[0039]

Therefore, the reproduction layer 45 preferably is formed with a material such that movement occurs in accordance with the domain wall movement in the magnetic-domain enlarging layer 41 and a greater Kerr rotation angle is large. It should be noted that the same effect can be achieved even if a plurality of films are provided as the reproduction layers 45, as long as the layers are configured so that the layer closer to the substrate has a higher Curie temperature and that a domain wall moves along with the magnetic-domain enlarging layer 41.

[0040]

The control layer 44 has a Curie temperature lower than the Curie temperature of the magnetic-domain enlarging layer 41 and higher than the Curie temperature T_{C2} of the intermediate layer 42, and is made of a magnetic material having a greater domain wall coercive force. Further, this layer, if in a single layer form, becomes a substantially compensation composition at room temperature, and preferably is a magnetic film in a perpendicular magnetization state.

[0041]

In Fig. 4, magnetic moments of this layer are not directed in the perpendicular direction. This is because the layer is thinly formed as compared with the magnetic-domain enlarging layer 41 and the

intermediate layer 42, and the layer has weakened perpendicular magnetic anisotropy when being interposed between magnetic layers in the in-plane magnetization state on the upper and lower sides.

[0042]

The following shows a specific example of a magneto-optical recording medium of Embodiment 2. A polycarbonate substrate having a track pitch width of 0.8 μm, recording-use grooves with a depth of 55 nm and a width of 0.6 μm was used as the substrate. Measurement of recording/reproduction signals was carried out exclusively at groove sections. As to the layer configuration, an interference layer made of SiN with a thickness of 80 nm, a reproduction layer 45 made of GdFeCoAl with a thickness of 20 nm (Curie temperature of 260°C), a magnetic-domain enlarging layer 41 made of GdFeCoAl with a thickness of 20 nm (T_{C1} = 210°C), a control layer 44 made of TbFeCo with a thickness of 5 nm (Curie temperature, 170°C), an intermediate layer 42 made of GdFeAl with a thickness of 10 nm (T_{C2} = 160°C), a recording layer 43 made of TbFeCo with a thickness of 80 nm (T_{C3} = 310°C), and a protective layer made of SiN with a thickness of 50 nm were formed successively under the same film forming conditions as those of Example 1.

[0043]

The temperature critical point at which the intermediate layer 42 makes a transition from an in-plain magnetization film to a perpendicular magnetization film was set to 90°C. Here, since the tendency that the perpendicular magnetization anisotropy in the vicinity of the Curie temperature decreases is intensified in the case where the critical point of the second magnetic layer is 100 or more degrees lower than T_{C2}, the critical point preferably is higher than (T_{C2} – 100)°C. Further, in the case where the critical point approaches to T_{C2}, a range in which the transfer from the third magnetic layer to the first magnetic layer occurs is narrowed, and defects are observed in reproduction signals. Therefore, to obtain signals with wider reproduction power margins, the critical point is set to be higher than (T_{C2} – 100)°C, and to obtain excellent reproduction signal characteristics by controlling the magnetic coupling between layers, the critical point preferably is in a range from (T_{C2} – 80)°C to (T_{C2} – 20)°C.

[0044]

Further, though the Curie temperature of the intermediate layer 42 is set to be 160°C in Embodiment 2, a domain wall movement was observed

in the case where it was in a range of 120°C to 200°C. However, to obtain a higher CN value, it is appropriate that the Curie temperature of the intermediate layer 42 is 130°C to 160°C. In another example also, a magnetic film having a Curie temperature in this temperature range was used as the intermediate layer 42.

[0045]

In the magneto-optical recording medium of Example 2, carriers were measured with a recording mark length being varied. The measurement result is shown in Fig. 5. For comparison, carriers of a recording mark length in the case where the reproduction layer and the control layer were omitted are shown. This is shown as Comparative Example 3 in Fig. 5. It should be noted that the reproduction power was the same, that is, 2.0 mW.

[0046]

In Comparative Example 3, since the Curie temperature of the magnetic-domain enlarging layer 11 was low, the Kerr rotation angle was small, and the carrier was low with any recording mark length. In the present embodiment, by inserting the reproduction layer 45 having a Curie temperature of 40°C higher than that of the magnetic-domain enlarging layer 41, the carrier value is enhanced on the whole.

[0047]

Further, without the control layer, the carrier degraded at a specific recording mark length. This is called ghost signal, which is seen with respect to a signal with a specific frequency. In the present embodiment, the transfer movement called as ghost signal can be suppressed.

[0048]

The driving power for the domain wall movement in the magnetic-domain enlarging layer 41 utilizes a temperature gradient ahead in the traveling direction of the laser beam. A temperature gradient occurring behind the laser beam is more gradual than that ahead the laser beam, and a domain wall driving force is induced. The domain wall movement causes noises of original reproduction signals, and therefore, several proposals have been made. To suppress the domain wall movement occurring behind the laser beam, magneto-optical reproduction utilizing a control layer is effective, which is reported by "Ghostless Signal Reproduction with the Domain Wall Displacement Detection Method" T. Shiratori et al., Proceedings of MORIS '99, Supplement, No. S1, pp.145-146.

[0049]

The control of a ghost signal by the control layer 44 can be explained as follows. In Fig. 4, behind the laser beam, the film temperature lowers as the medium goes rightward. Since the control layer 44 has a Curie temperature higher than the Curie temperature of the intermediate layer 42, a magnetic order is generated in the control layer 44 earlier than in the intermediate layer 42. In Fig. 4, it is designated as ΔX. In other words, since an exchange coupling with the magnetic-domain enlarging layer 41 having a greater domain wall coercive force is formed in the portion ΔX, the domain wall movement does not occur behind the laser beam. Therefore, the carrier-value-dependency of the recording mark is eliminated.

[0050]

Without a control layer, carriers increase/decrease according to marks, whereas in the present embodiment, with the control layer 44, suppression of the domain wall movement behind the laser beam is made possible. Further, since the intermediate layer 42 is an in-plain magnetization film at room temperature, the exchange coupling between the recording layer and the magnetic-domain enlarging layer can be broken. Therefore, in the magneto-optical recording medium of the present embodiment, the control layer 44 is very effective.

[0051]

(Embodiment 3)

Fig. 6 is a view illustrating a configuration of a magneto-optical recording medium of embodiment 3. Embodiment 3 is characterized by the same configuration and the same recording/reproducing operation as those of Embodiment 1 except that a magnetic-domain enlarging layer 61 is a perpendicular magnetization film at room temperature. In the present embodiment, the compensation composition temperature of the magnetic-domain enlarging layer 61 is adjusted so that it becomes in a perpendicular magnetization state in a temperature range from room temperature to a Curie temperature T_{C2}.

[0052]

The magnetic-domain enlarging layer 61 used in the present embodiment is made of a magnetic thin film material having a great domain-wall-energy density σ1 even at room temperature so that a driving force F1 = –σd/dx that promotes movement of a domain wall, which is exerted to a domain wall present at a point x, is increased. Therefore, the

domain wall enlarging layer 61 is in a state such that it has a difficult in forming a magnetic domain. Therefore, since it is in a state such that a small domain cannot exist stably, magnetic moments in the magnetic-domain enlarging layer 63 are aligned in the same direction in a region where the film temperature is in a temperature range lower than the critical point, and no domain wall is present.

[0053]

However, as the temperature of the recording film rises, the intermediate layer 62 becomes in a perpendicular magnetization state, and an exchange coupling force is exerted between the magnetic-domain enlarging layer 61 and the recording layer 63. In such a case, which is lower, either energy with which a domain wall is formed between the recording layer 63 and the magnetic-domain enlarging layer 61, or energy with which the magnetic-domain enlarging layer 61 transfers recording marks of the recording layer and forms magnetic domains in the magnetic-domain enlarging layer 61, determines whether or not information is transferred to the magnetic-domain enlarging layer 61.

[0054]

In the present embodiment, the film configuration is designed so that in the case where an exchange coupling force is exerted between the magnetic-domain enlarging layer 61 and the recording layer 63, the interface domain-wall-energy between the recording layer 63 and the magnetic-domain enlarging layer 61 becomes extremely high. Therefore, when the film temperature reaches the critical point and the intermediate layer 62 becomes a perpendicular magnetization film, the information in the recording layer 63 is transferred.

[0055]

When the medium moves rightward, the film temperature reaches T_{C2} or above, and the magnetic moments in the intermediate layer 62 move at random. Therefore, the exchange coupling stops working. Here, since a temperature gradient is generated, a change in the domain-wall-energy density is great, and the driving force $F1 = -d\sigma 1/dx$, which promotes the domain wall movement in the magnetic-domain enlarging layer 61 is predominant. Therefore, only a magnetic domain transferred from the recording layer 63 as a result of irradiation by a laser beam is enlarged in the magnetic-domain enlarging layer 61, and is reproducible as a signal with a greater amplitude.

[0056]

The following describes a specific example of a magneto-optical recording medium of Embodiment 3. As the substrate, a polycarbonate substrate of a sample servo type was used. As component layers, an interference layer made of SiN with a thickness of 80 nm, a magnetic-domain enlarging layer 61 made of GdFeCoAl with a thickness of 20 nm (T_{C2} = 220°C), an intermediate layer 62 made of GdFeCoAl with a thickness of 10 nm (T_{C2} = 140°C), a recording layer 63 made of TbFeCo with a thickness of 80 nm (T_{C3} = 290°C), and a protective layer made of SiN with a thickness of 50 nm were formed successively under the same film forming conditions as those for Example 1.

[0057]

The sample servo substrate does not have a physical obstacle between a target track and adjacent tracks as compared with a land-groove substrate on which guide grooves are formed, like those used in Examples 1, 2, and the like. Therefore, it does not have a shape such that it obstacles the driving force with respect to a domain wall. However, in the case where a recording film in the conventional magnetic-domain enlargement reproduction style is formed on the sample servo substrate, a magnetic domain in the recoding layer is transferred to the magnetic-domain enlarging layer also in an adjacent track. Thus, the domain wall movement from the adjacent track becomes predominant, and signal reproduction cannot be performed.

[0058]

On the other hand, in the present example, as described above, the sample servo substrate has no groove, and hence, magnetic association with adjacent tracks are intensive, whereas marks recorded in the recording layer 63 are not transferred to the magnetic-domain enlarging layer 61 in a portion no subjected to irradiation with a laser beam where the intermediate layer 62 is in an in-plain magnetization film. This shows that when the film temperature reached the critical point due to the irradiation with a laser beam, a recording mark in the recording layer 63 was transferred to the magnetic-domain enlarging layer 61, and was enlarged and reproduced. As a result, a recording mark length of 0.15 μm and a CN ratio of 41.2 dB were obtained. Here, since a signal quantity was greater than that of the conventional example, it can be assumed that the domain wall movement was extended not only in the track direction but also in the

radial direction.

[0059]

(Embodiment 4)

Next, Embodiment 4 is described. The configuration thereof is shown in Fig. 7. Embodiment 4 is characterized by the same configuration and the same recording/reproducing operations as those of Embodiment 1 except that a non-magnetic layer 74 made of SiN with a thickness of 10 nm was interposed between an intermediate layer 72 and a recording layer 73. The magnetic characteristics of a magnetic-domain enlarging layer 71 made of DgFeCoAl (T_{C1} = 230°C), an intermediate layer 72 made of GdFeCoAl with a thickness of 10 nm (T_{C2} = 130°C), a recording layer 73 made of TbFeCo with a thickness of 80 nm (T_{C3} = 320°C), and the like are he same as those of Embodiment 3. Therefore, descriptions of the same are omitted here. Here, the present embodiment has a film configuration such tat the exchange coupling is blocked by the non-magnetic layer 74, while a transfer magnetic field from the recording layer 73 is increased in a temperature range in the vicinity of the critical point. This makes the transfer from the recording layer 73 to the magnetic-domain enlarging layer 71 possible, thereby realizing the magnetic-domain enlargement reproduction. Consequently, reproduction signals with a mark length of 0.2 μm and a CN ratio of 40 dB were obtained.

[0060]

It should be noted that the substrate and the film configuration of Examples 1 to 4 are examples, and the present invention is characterized by transfer of magnetization information in the recording medium to the magnetic-domain enlarging layer at a temperature higher than room temperature, and enlargement and reproduction of the same. As long as the present invention maintains the foregoing characteristics, the present invention is not limited to the configurations of the embodiments described above, and may be modified in various embodiments. The following describes examples of the substrate and the thin film magnetic materials.

[0061]

The transparent substrate may be formed by using glass, polycarbonate resin, etc. For tracking servo, a substrate configured to have guide grooves formed by the continuous servo method so that signals are recorded/reproduced by lands or grooves alone, a sample servo type substrate, or any type can be used unselectively.

[0062]

Layers composing a magneto-optical recording medium can be formed by, for instance, continuous sputtering with a sputtering device, vapor deposition, etc. The interference layer is provided for enhancing the magneto-optical effect and protecting magnetic layers, and is formed with a transparent dielectric material such as Si_3N_4, AlN, AlSiN, SiO_2, SiO, ZnS, MgF_2, etc.

[0063]

The third magnetic layer can be made of a rare earth-transition metal amorphous alloy, for instance, TbFeCo, DyFeCo, TbDyFeCo, etc., which has great perpendicular magnetic anisotropy and coercive force such that small recording bits can be formed and the formed recording bits can be stored stably, and recording information is held by magnetization in magnetic domains in the layer, which are directed upward or downward. The layer may be configured by using a perpendicular magnetization film made of garnets, Pt/Co, Pd/Co, etc., so that information can be transferred magnetically to another layer. It should be noted that the coercive force of the third magnetic layer at room temperature is greater than the coercive force of the first magnetic layer at room temperature that will be described later.

[0064]

The second magnetic layer is made of a rare earth-transition metal amorphous alloy as another magnetic layer, and its composition has to be adjusted so that it is an in-plain magnetization film at room temperature and makes a transition to a perpendicular magnetization film at a temperature higher than a critical point. This is because, to describe specifically, the second magnetic layer makes a transition from an in-plain magnetization film to a perpendicular magnetization film as the temperature rises, thereby forming magnetic coupling such as exchange coupling exerted between the third magnetic layer and the first magnetic layer, and at a temperature higher than T_{C2}, the second magnetic layer functions for breaking the magnetic coupling such as exchange coupling between the third magnetic layer and the first magnetic layer.

[0065]

The first magnetic layer may be formed using, for instance, a rare earth-transition metal amorphous alloy having a small perpendicular magnetic anisotropy such as GdCo, GdFeCo, GdFe, NdGdFeCo, etc. or a

bubble memory material such as garnet, so that the layer has a smaller domain wall coercive force and a greater domain wall movement degree as compared with the other magnetic layers. Alternatively, thermal characteristics thereof may be adjusted by further adding a metal layer made of Al, AlTa, AlTi, AlCr, Cu, etc. Still alternatively, a protective coating made of a polymer resin may be added.

[0066]

Next, a method and a device for recording/reproducing a magneto-optical recording medium according to an embodiment of the present invention are described below. The configuration is such that information is recorded, reproduced, and erased with a laser beam. Upon reproduction, a laser beam spot is moved relatively to a magneto-optical recording medium, while the medium is irradiated from a reproduction layer side. A temperature distribution with a gradient is formed with respect to the direction in which the beam spot is moved, so that a temperature distribution having a temperature region in which a force exerted to a domain wall formed in the reproduction layer so as to move the domain wall formed in the reproduction layer toward a higher temperature is greater than a coupling force generated by the recording layer via an intermediate layer is formed in the reproduction layer. By so doing, information enlarged and formed in the reproduction layer is detected as a change in a polarization plane of a reflected light from the beam spot. This is the method for reproducing a magneto-optical recording medium.

[0067]

[Effects of the invention]

As described above, by using a magneto-optical recording medium of the present invention, a signal with an amplitude at the same level as that of a large magnetic domain can be obtained from a small magnetic domain. Therefore, the information recording density on a medium can be enhanced significantly, and the transfer velocity can be improved significantly. Further, the compatibility with conventional media is facilitated, and still further, margins upon reproduction can be increased by suppression of cross talks. Therefore, it achieves excellent effects such as downsizing of a device and reduction of cost.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1] Fig. 1 is a cross-sectional view explaining a magnetization state of

a magneto-optical recording medium according to Embodiment 1 of the present invention.

[FIG. 2] Fig. 2 is a cross-sectional view of a magneto-optical recording medium of Embodiment 1 of the present invention.

[FIG. 3] Fig. 3 is a characteristic diagram showing reproduction power dependency of a C/N ratio of Embodiment 1 of the present invention.

[FIG. 4] Fig. 4 is a view explaining a magneto-optical recording medium of Embodiment 2 of the present invention and principles of reproduction of the medium.

[FIG. 5] Fig. 5 is a view showing dependency of a C/N ratio on mark length obtained in Embodiment 2 of the present invention.

[FIG. 6] Fig. 6 is a cross-sectional view explaining a magneto-optical recording medium of Embodiment 3 of the present invention and reproduction principles of the same.

[FIG. 7] Fig. 7 is a cross-sectional view explaining a magneto-optical recording medium of Embodiment 4 of the present invention.

[FIG. 8] Fig. 8 is a schematic view explaining reproduction principles of a conventional domain wall movement-type magnetic-domain enlargement magneto-optical recording medium.

[Explanation of letters or numerals]

10, 40 interference layer

11, 41, 61, 71 magnetic-domain enlarging layer

12, 42, 62, 72 intermediate layer

13, 43, 63, 73 recording layer

14, 46 protective layer

15, 47 substrate

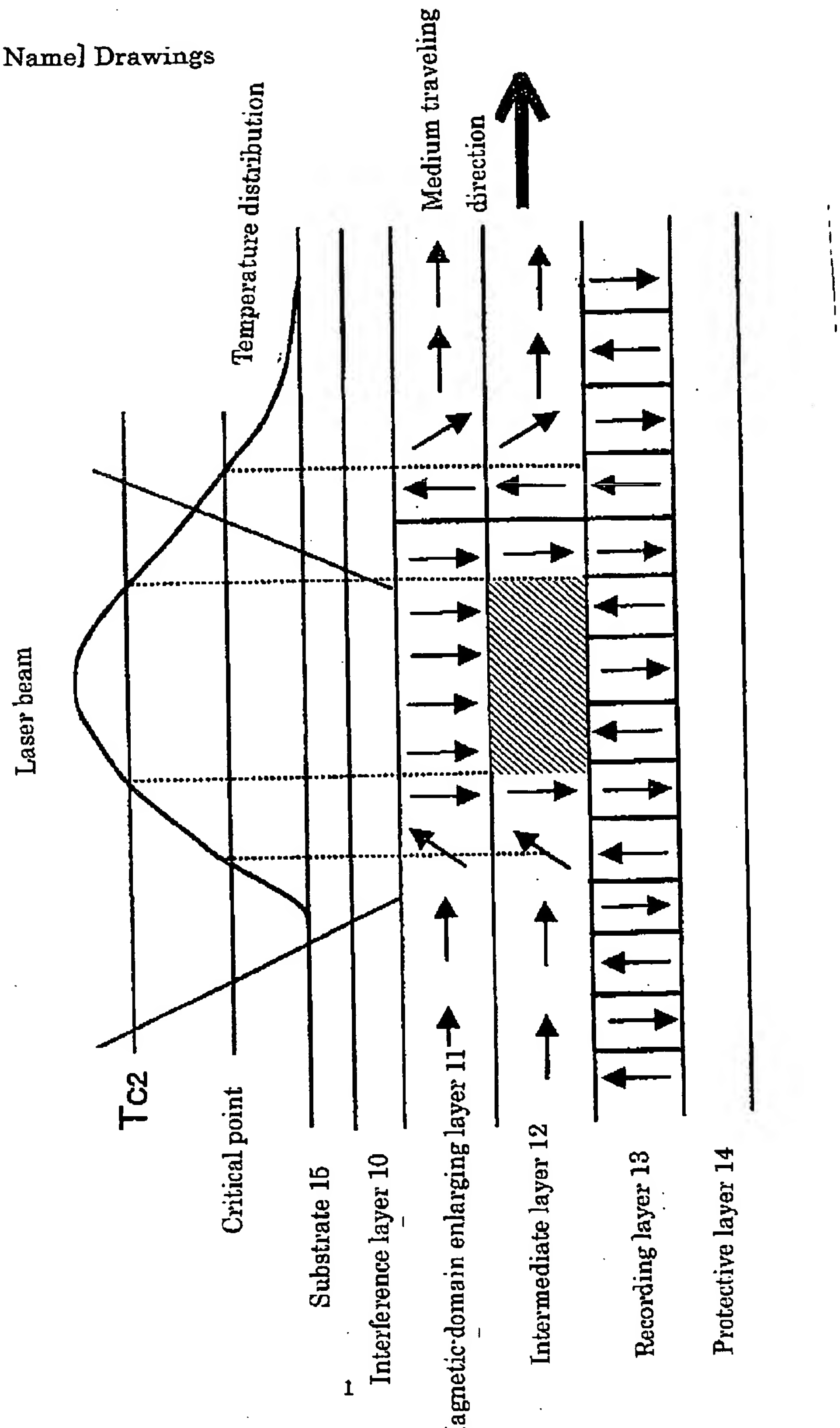
44 control layer

45 reproduction layer

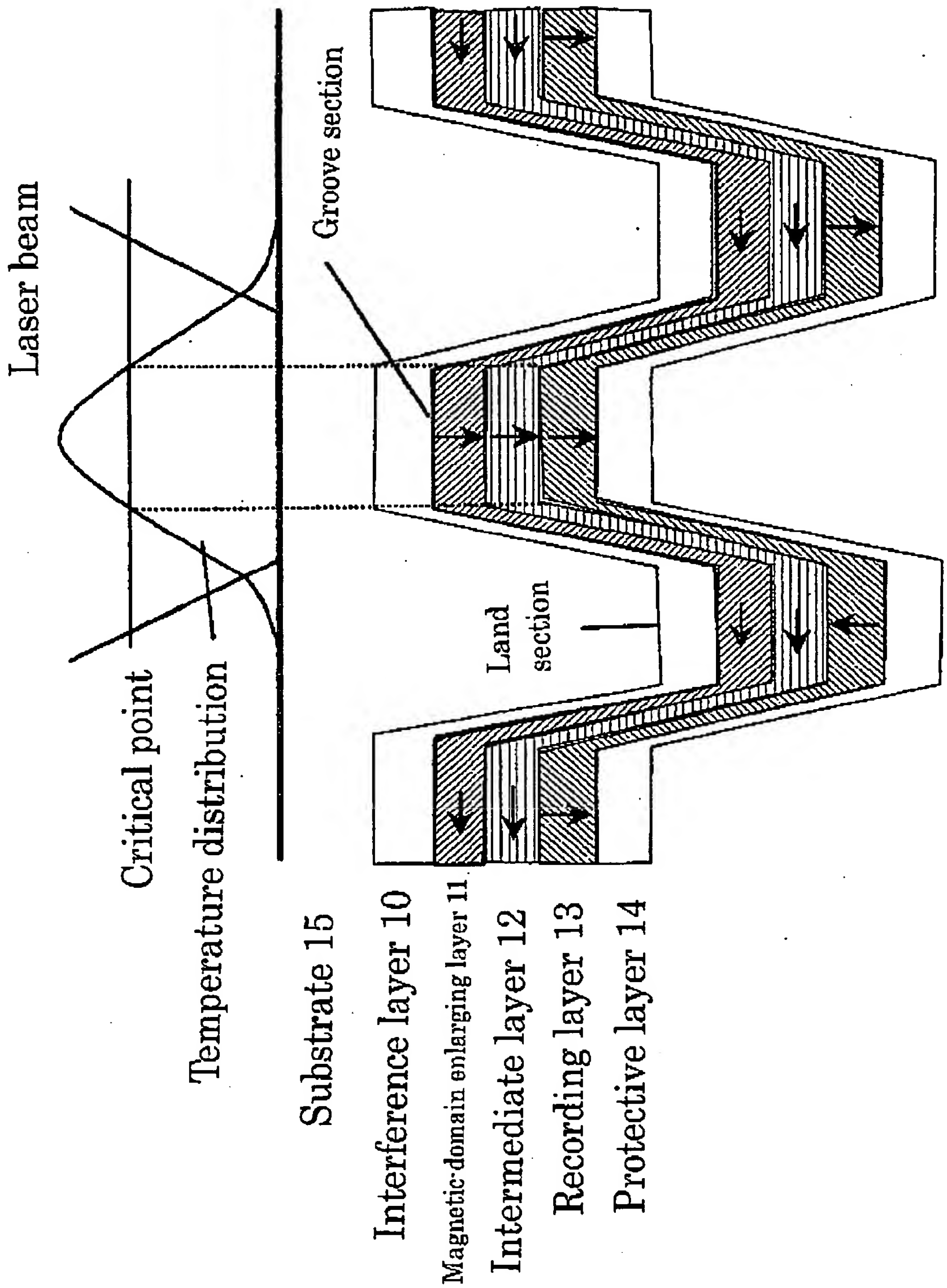
74 non-magnetic layer

[Document Name] Drawings

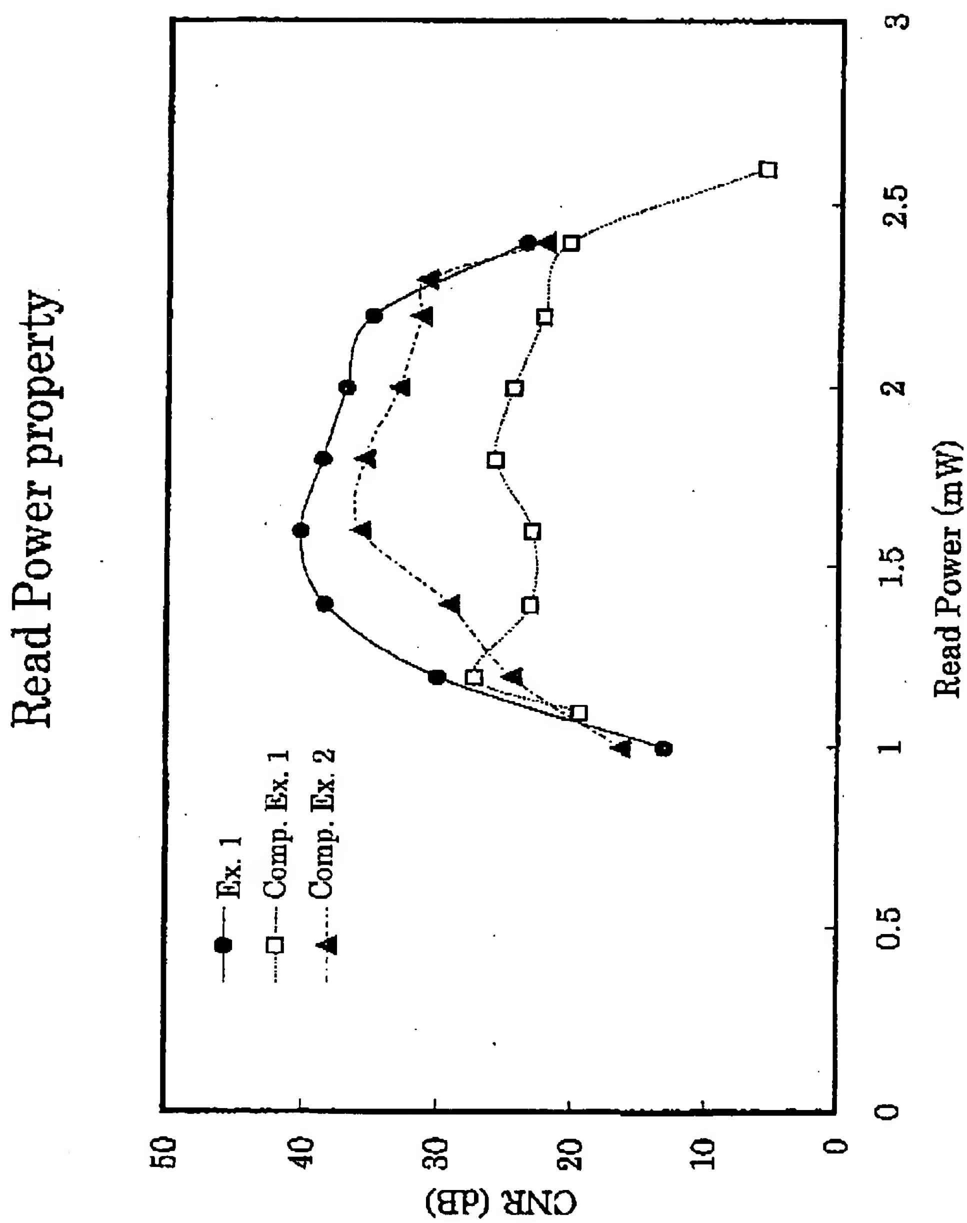
[FIG. 1]



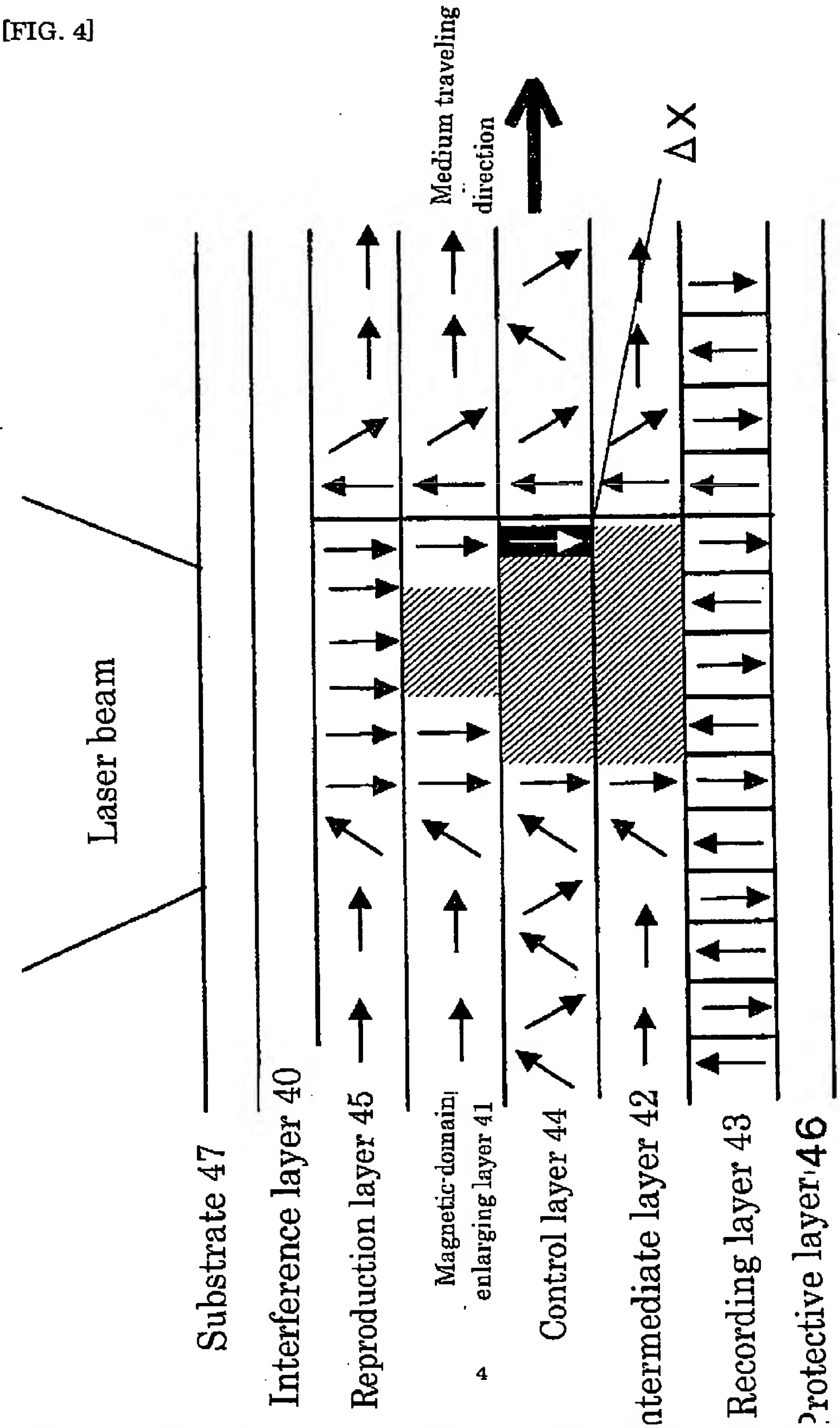
[FIG. 2]


Laser beam
Critical point
Temperature distribution
Substrate 15
Interference layer 10
Magnetic-domain enlarging layer 11
Intermediate layer 12
Recording layer 13
Protective layer 14
Groove section
Land section

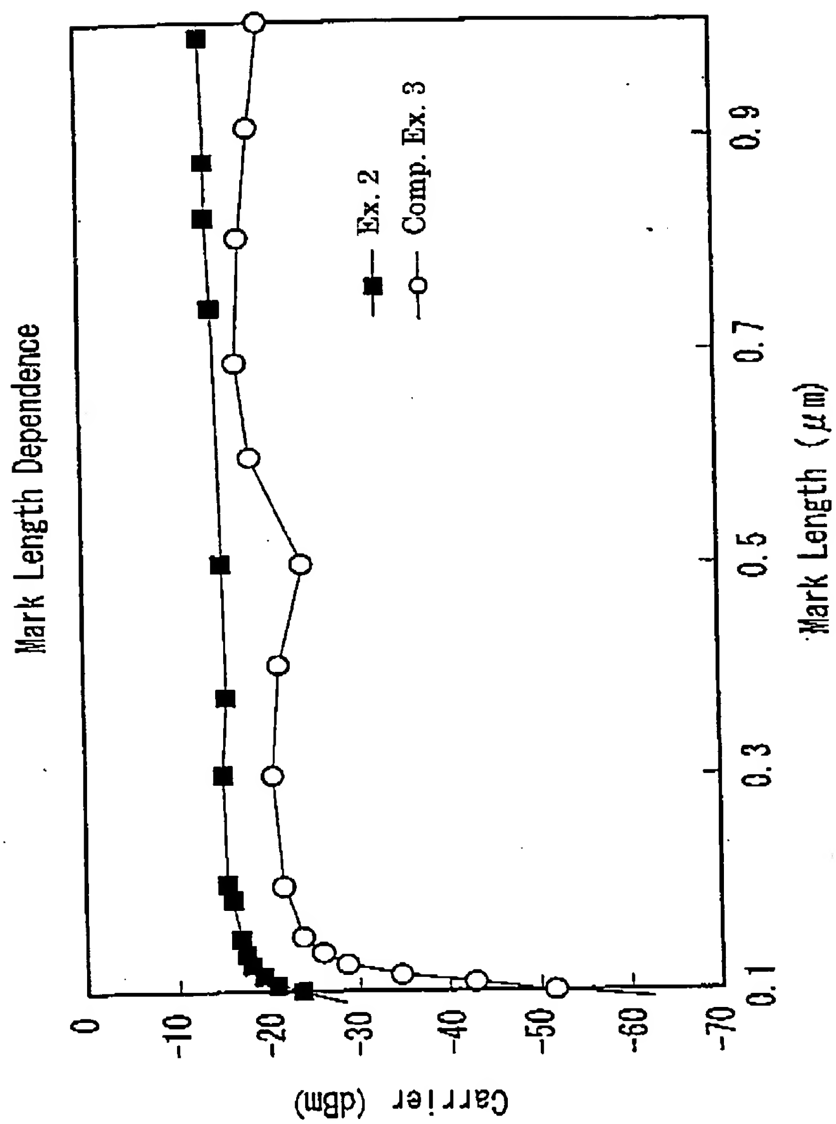
[FIG. 3]


Read Power property
Ex. 1
Comp. Ex. 1
Comp. Ex. 2
CNR (dB)
50
40
30
20
10
0
Read Power (mW)
0
0.5
1
1.5
2
2.5
3

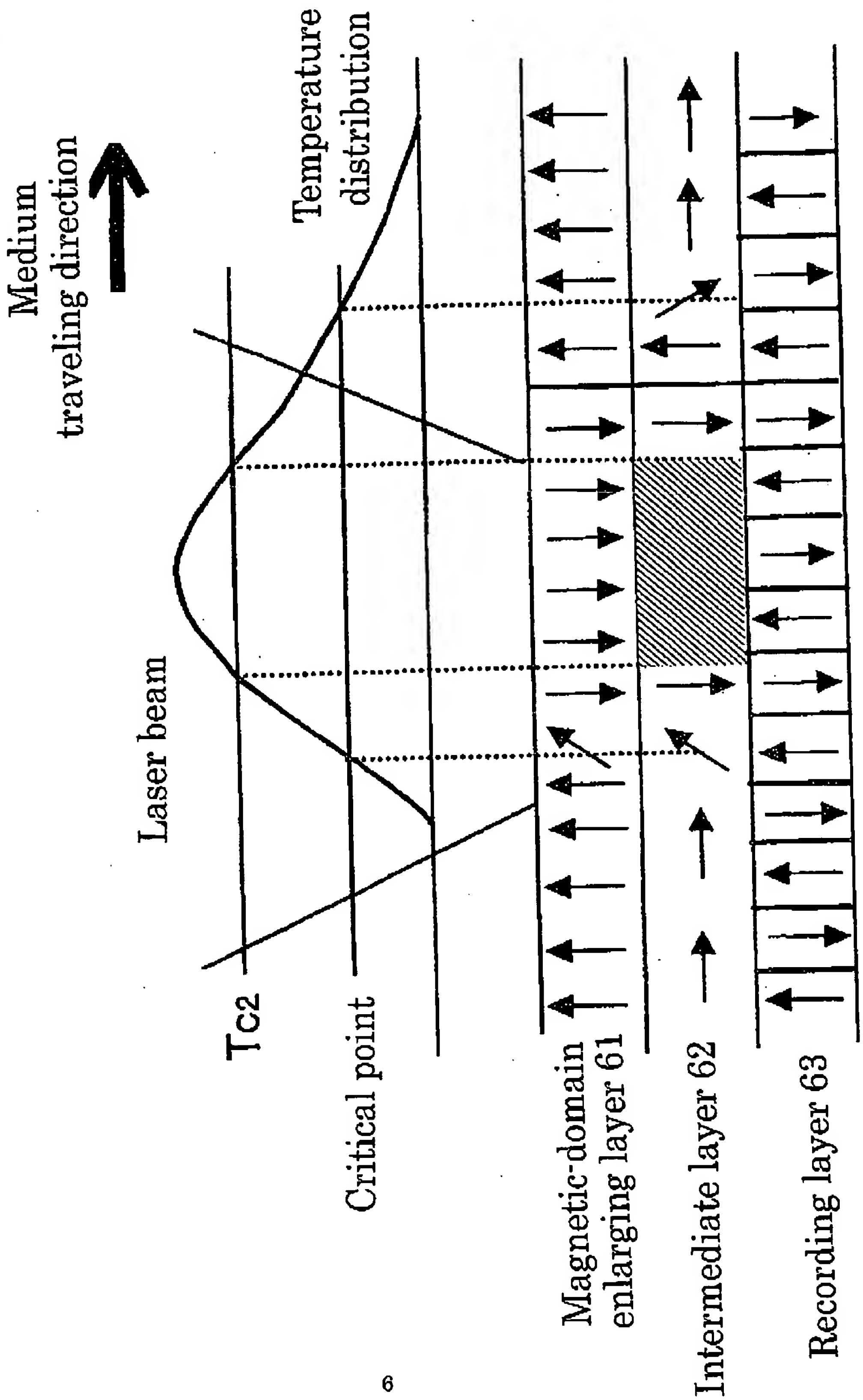
[FIG. 4]


Medium traveling direction
ΔX
Laser beam
Substrate 47
Interference layer 40
Reproduction layer 45
Magnetic-domain enlarging layer 41
Control layer 44
ntermediate layer 42
Recording layer 43
Protective layer 46

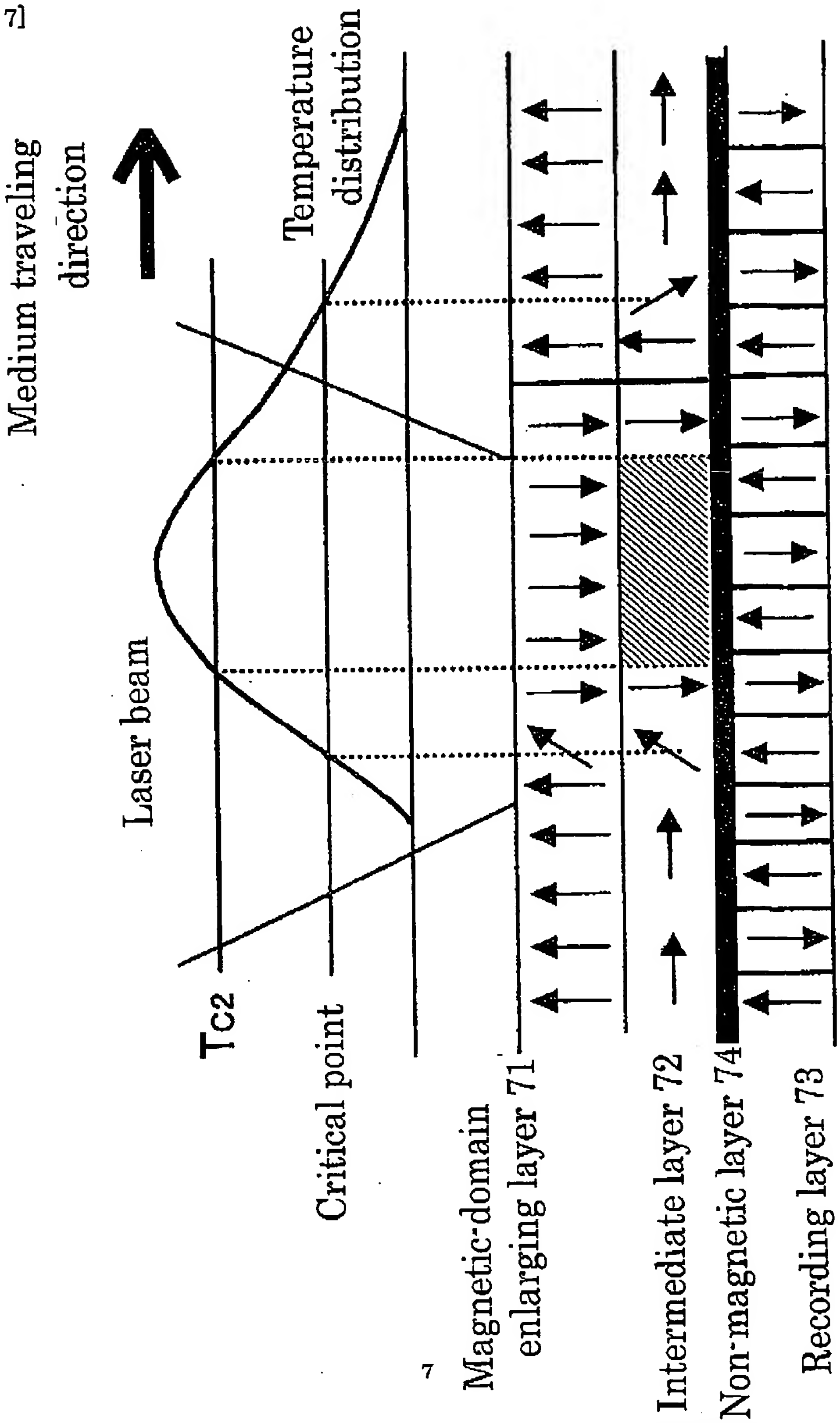
[FIG. 5]


Mark Length Dependence
Ex. 2
Comp. Ex. 3
0
-10
-20
-30
-40
-50
-60
-70
Carrier (dBm)
0.1
0.3
0.5
0.7
0.9
Mark Length (μm)

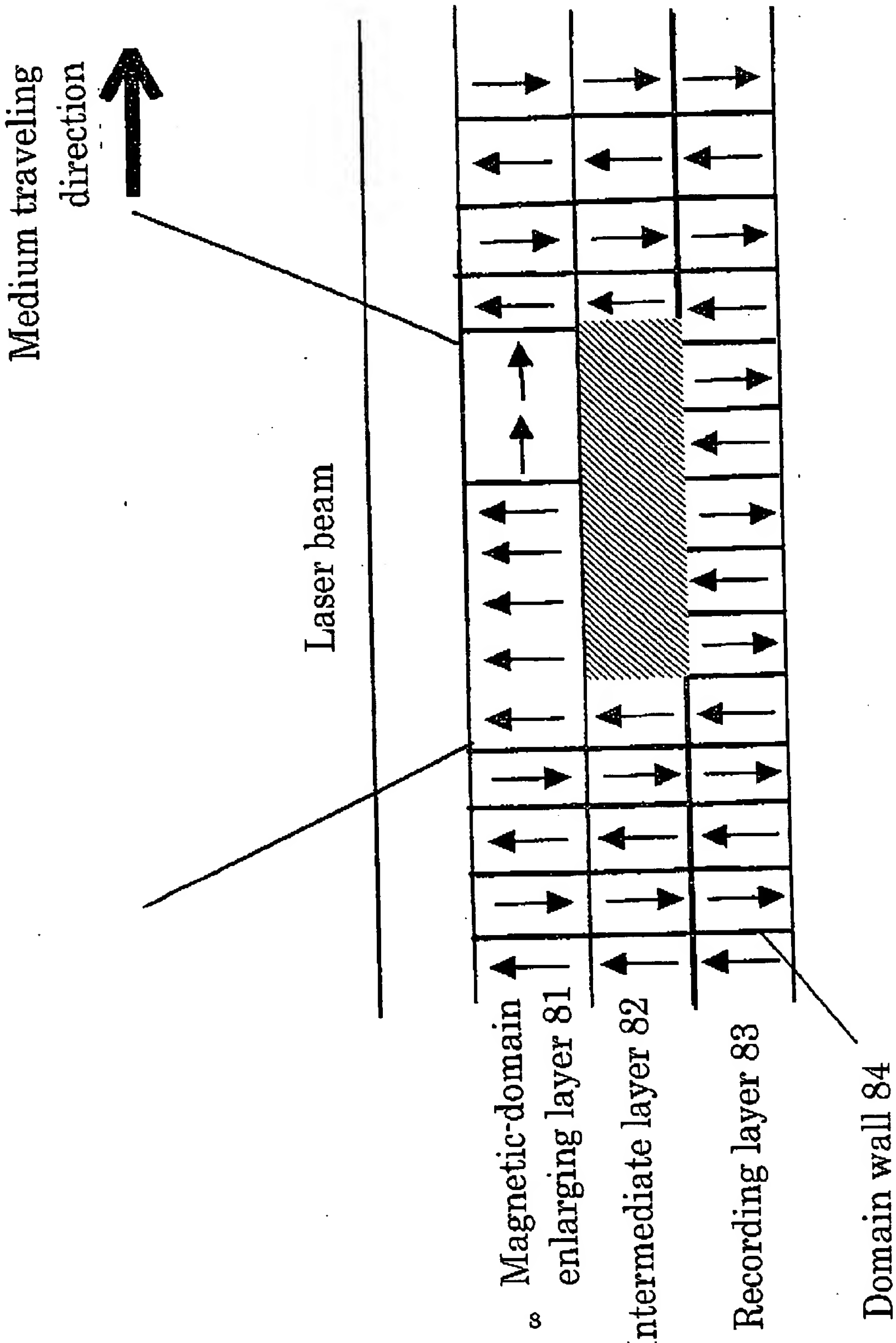
[FIG. 6]


Medium traveling direction
Temperature distribution
Laser beam
Tc2
Critical point
Magnetic-domain enlarging layer 61
Intermediate layer 62
Recording layer 63

[FIG. 7]


Medium traveling direction
Temperature distribution
Laser beam
Tc2
Critical point
Magnetic-domain enlarging layer 71
Intermediate layer 72
Non-magnetic layer 74
Recording layer 73

[FIG. 8]


Medium traveling direction
Laser beam
Magnetic-domain enlarging layer 81
Intermediate layer 82
Recording layer 83
Domain wall 84

[Document Name] ABSTRACT

[Abstract]

[Object] To provide a magneto-optical recording medium that provides excellent domain-wall movement and domain-wall enlargement, and improves signal intensity with a simple configuration.

[Means to Solve the Problems] A magneto-optical recording medium is configured so as to include a magnetic-domain enlarging layer having a small domain-wall coercive force, an intermediate layer, and a recording layer that are laminated on a transparent substrate. The intermediate layer exhibits a stable in-plain magnetization film state at room temperature, and has magnetic characteristics such that it comes to form exchange coupling between the recording layer and the magnetic-domain enlarging layer as temperature rises. By so doing, the breaking of the magnetic coupling between a target track and adjacent tracks is enabled, whereby the signal intensity is increased.

[Selected Figure] Fig. 2

Verification of Translation

US Patent Application No.: 09/975,525

Title of the Invention: MAGNETO-OPTICAL RECORDING MEDIUM AND REPRODUCING METHOD

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am the translator of the documents attached and I state that the following is a true translation to the best of my knowledge and belief of a full text of JP2000 – 310394A (Date of application : October 11, 2000).

At Osaka, Japan
DATED this 24/12/2003 (Day/Month/Year)

Signature of the translator Harumi Sasaki

Harumi SASAKI

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: October 11, 2000

Application Number: Patent Application No. JP2000-310394

Applicant(s): Matsushita Electric Industrial Co., Ltd.

July 9, 2001
Commissioner, Patent Office: Kozo OIKAWA